

2013 International Conference on Virtual and Augmented Reality in Education

## Improving Spatial Skills: An Orienteering Experience in Real and Virtual Environments With First Year Engineering Students

Cristina Roca González <sup>a\*</sup>, Jorge Martín-Gutiérrez <sup>b</sup>, Melchor García Domínguez <sup>a</sup>

Alejandra Sanjuán HernanPérez <sup>a</sup>, Carmen Mato Carrodegas <sup>c</sup>

<sup>a</sup>Universidad de La Laguna, Escuela Superior de Ingeniería Civil e Industrial. Campus de Anchieta, 38206 La Laguna, Tenerife. Spain.

<sup>b</sup>Universidad de Las Palmas de Gran Canaria, Dpto. Cartografía y Expresión Gráfica en la Ingeniería. 35017 Las Palmas de GC. Spain.

<sup>c</sup>Universidad de Las Palmas de Gran Canaria, Dpto. Didácticas Especiales. 35004 Las Palmas de GC. Spain.

---

### Abstract

In this work we present the results obtained from an experience performed with freshmen students of the Industrial Engineering degree at Las Palmas de Gran Canaria University aiming for improvement of their spatial abilities. The work linked to spatial abilities show a great lack of uniformity according to the adopted terminology as a consequence of different approaches, researchers' field of study and the research's scale. But all research agree on the relationship between a high level of spatial ability and the possibility of success in certain professional careers and university degrees such as engineering which is our actual case. The pilot study described in this paper, aims to improve the Spatial Orientation component of spatial abilities and for this we conducted two experiences or trainings based on orienteering sports: one was performed in a real environment meanwhile the other took place in a virtual environment. The results show that this component can be trained and improved in both environments without finding any significant difference between both types of training.

© 2013 The Authors. Published by Elsevier B.V. Open access under [CC BY-NC-ND license](#).

Selection and peer-review under responsibility of the programme committee of the 2013 International Conference on Virtual and Augmented Reality in Education

**Keywords:** Spatial abilities; Spatial orientation; Environmental scale; Orienteering; Virtual worlds

---

---

\* Corresponding author. Tel.: +34928451958; fax: +34928451873

E-mail address: [croca@dcegi.ulpgc.es](mailto:croca@dcegi.ulpgc.es)

## 1. Introduction

Most part of our sensations, anything that we experience or learn is acquired through the visual system. Our world could not be understood without the graphic sketches, which have been drawn since prehistory, and now used for designing every product and service demanded by an ever increasing technological society.

The spatial vision is understood as the ability to visualize and manipulate objects in our minds. It's not just an important skill widely recognized in the engineering field, but it's also highly regarded in many other fields. So, van der Geer points out that the spatial vision is important for succeeding in fields such as Biology, Chemistry, Mathematics and Natural Science [1].

For predicting the success in university studies, some universities commonly consider academic records and physics or mathematics grades when the case belongs to engineering degrees. Some studies have revealed an existing correlation between ability and success in other engineering fields.

One of the problems found while revising references about spatial abilities is the contradiction about its definition. We may find the same term for identical components or even different terms with the same descriptions. Besides, there is no common agreement about the number of components of that ability, varying between two and ten depending on the authors. Despite the lack of agreement about the definition of this concept, we may outline the one belonging to Linn & Petersen [2] as the "skill in representing, transforming, generating, and recalling symbolic, non-linguistic information".

The structure of the components belonging to the spatial ability has been subject to study since the 40s. Commonly, the spatial ability has been considered to be composed by three components. In Linn & Petersen [2] as well as Lohman's [3] works, the three components are: *spatial perception*, *orientation* or *spatial rotation* and finally, the *spatial visualization*. *Spatial perception* measures a person's ability to sense horizontally or vertically, *spatial rotation* indicates the ability to quickly rotate any two dimensions figures as well as three dimensions objects through imagination and *spatial visualization* assesses the ability to manipulate the spatial information belonging to simple objects through complex operations.

Other researchers such as McGee [4] y Maier [5] propose five main components: *spatial relations*, *spatial perception*, *spatial visualization*, *mental rotation* and *spatial orientation*. In this classification, we may observe the difference while considering *mental rotation* and *spatial orientation*.

We found a couple of issues during the bibliographic revision of the spatial abilities' concept. In first place, the studies don't provide similar results; meanwhile many studies identify the *spatial orientation* inside their rankings [4-6], others don't [7] and even among those which didn't include them, there is no common agreement according to its definition. Besides, these studies don't pay attention to the dynamic and environmental components, which are considered as quite important factors among the spatial abilities field [8].

Another factor which should be considered is the environmental scale where spatial abilities should be tested [9,10]. Montbello [11] proposes that due to the fact that the human motor and perceptual system interacts in a different way with space depending on scale, there are many psychological systems involved in processing that information in different scales. In a large scale, we don't have any chance to obtain all spatial information referring to any natural and artificial elements which belong to the individual's personal environment. This kind of abilities is very important in movements and navigation. In this sense, we find another taxonomy which regards both dynamic and spatial components proposed by Gary L. Allen[12], sorting the spatial components across three functional families. The first one should answer the '*What is this?*' question gathering anything referring to the identification and manipulation of small still objects such as what happens when a written paper test is being solved. The second question is '*Where is it?*' including situations where the individual and/or the object may be moving or motionless such as when a ball's trajectory is being calculated. The third question should answer to '*Where am I?*' referring to an individual moving across a big scale environment full of still objects such as buildings or vegetation.

## 2. The aim of present study

Our aim is performing trainings for improving the freshmen's spatial orientation component of spatial abilities enrolled in the engineering graphics subjects on engineering degrees taught at the Civil and Industrial engineering school from Las Palmas de Gran Canaria University. If this training is successful, it will help students easing any studying issues while obtaining better academic results on this subject.

## 3. Hypothesis

Until now, just a few studies have attempted to relate spatial abilities at different scales, ie, whether the results obtained by measuring spatial skills with psychometric test paper, can predict success on large scale task [13, 14]. Regardless of any correlation, in this work we may assume the spatial orientation as a component of spatial ability so we will try to improve it through specific training designed for this experience. Therefore, the spatial orientation will improve which will help the student towards a better understanding of the Graphic Design subject on engineering.

The training was chosen having in mind that we may focus on tests performed over large environments, so we opted for an orienteering race. Besides, we wanted to evaluate the results performing those tests over two kinds of environments: a real one and a virtual one.

Our hypothesis is that performance of that training may improve the spatial orientation of the students.

## 4. Participants

The participants were 79 freshmen students from the Las Palmas de Gran Canaria University belonging to the Industrial Engineering degree. The average age and standard deviation (SD) was 18.8 (1.3) between 18 and 24 years old for men meanwhile value was 18.8 (1.2) between 18 and 24 years old for women. They were split in two homogeneous groups for performing training as 30 of them undertook training in a real environment meanwhile 33 of them did it on a virtual one.

The experiences were performed in the first week of the first semester during the 2012-2013 academic course, so no student had attended classes of any kind from any Graphic Design subject on engineering before undertaking training. None of them had ever taken part on any orienteering races either. The orientation values were measured using a reliable measurement tool before performing the experience and after its completion: the Perspective Taking/ Spatial Orientation Test developed at the Santa Barbara University by Mary Hegarty et al. [15,16]

## 5. Experience 1: Real World Orienteering

Thirty participants took part in this experience (10 women and 20 men). The mean value and standard deviation (SD) was 18.7 (1.1) between 18 and 24 years. None of them declared having any previous experience in orienteering sports. For encouraging participation, the three top performers with best times will enjoy an upgrade on their marks as long as it's 4.5 or higher.

The experiment consisted of two phases, first of them 45 minutes long and in the classroom, an expert at orienteering explained the basis for this practice with emphasis on the use of the compass

There were some relevant changes respecting the usual orienteering race. During the race there weren't any geographic elements as well as any building or vegetation which could be used as a reference. Only distances or relative angles were available so they were shown on spot how to measure distances through steps on the plane's scale. Besides, as this wasn't any physical test, they were instructed not to run as celerity relied on the ability to orientate and not on swift movement.



Fig.1 Left. Expert giving instructions. Right. Students measuring distances through steps.

While using maps, the orienteering method will depend on the ability to interpret them – spatial relations will be established over symbols- and the ability to connect the map with the field and vice versa.

We also considered some common actions from this sport:

- Bringing the map and other race material (compass, card and control's description).
- Map orientation
- Map reading
- Choosing the right path.
- Deciding the most suitable technique

In our experience we omitted some actions for strengthening the desired meaning for the race. The experience took place in a football field where there were only architectonic elements available for setting spatial relations. But given the simplicity of a football field and how the orientation sense was meant to be trained, we omitted the architectonic elements by providing the students with a 'blind map' where the only display belonged to the relative layout of the beacons according to their angle and distance as well as the geographic north.

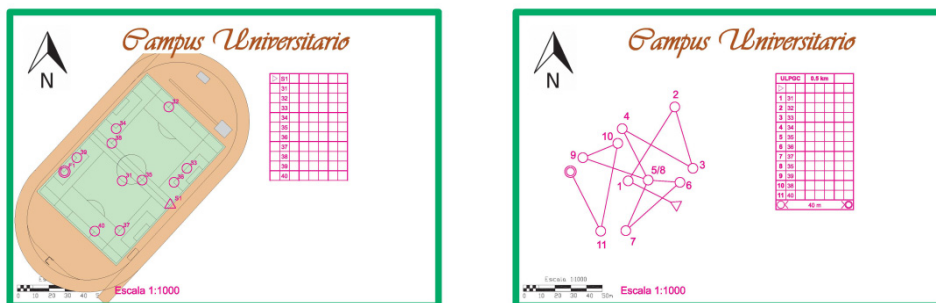


Fig.2 Left. Football field's map including beacons. Right 'blind map' provided to the participant.

For the second phase, the proper 'orientation race' indeed, there were two tracks designed with a similar length. The students were told that both paths were different, to avoid them following each other. So, they didn't know which path was being followed by the student who previously got into the field. Each student completed both paths, so the results obtained doesn't rely on pure luck.

For performing this test we used the Sportident system. This system is based on the SPORTident-Card, similar to a pen drive. During the race, the system compiles times and numeric codes from the control points. The output offers individual registry values for both intermediate and total times.

2/5/2013

[\[A\]](#) [\[B\]](#)

A Course (I): 11 KP

#	Name	Result	Start	1. ( 31 )	2. ( 32 )	3. ( 33 )	4. ( 34 )	5. ( 35 )	6. ( 36 )	7. ( 37 )	8. ( 38 )	9. ( 39 )	10. ( 40 )	11. ( 41 )	Finish
1	PAUL CABRERA OLOFFSON ...	00:02:50	14:33:13	00:17 2 00:31 2 00:44 1 01:02 2 01:17 2 01:27 2 01:45 2 01:58 2 02:13 2 02:25 2 02:40 1 00:02:50	00:17 2 00:14 1 00:13 2 00:18 2 00:15 1 00:10 2 00:18 2 00:13 2 00:15 1 00:12 1 00:15 1 00:10 1	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	2								
2	JAYIER EDUARDO MORENO ...	00:03:04	14:38:52	00:13 1 00:30 1 00:44 1 00:59 1 01:16 1 01:25 1 01:42 1 01:54 1 02:09 1 02:22 1 02:51 2 03:04 2 00:03:04	00:13 1 00:17 2 00:14 4 00:15 1 00:17 3 00:09 1 00:17 1 00:12 1 00:15 1 00:13 4 00:29 4 00:13 3	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	14								
3	SERGIO CUBAS MEDINA ...	00:03:35	14:38:04	00:19 4 00:37 3 00:52 3 01:17 3 01:39 3 01:51 3 02:14 3 02:27 3 02:48 3 03:00 3 03:25 3 03:35 3 00:03:35	00:19 4 00:18 4 00:15 6 00:15 5 00:22 7 00:12 7 00:23 6 00:13 2 00:21 5 00:12 1 00:25 3 00:10 1	00:02 00:04 00:02 00:07 00:07 00:02 00:05 00:00 00:04 00:00 00:04 00:00 00:10 00:00 00:00	4								
4	FRANCISCO HERNÁNDEZ GA...	00:03:46	14:37:27	00:23 6 00:52 6 01:08 6 01:26 6 01:47 4 01:57 4 02:19 5 02:36 4 02:51 4 03:05 4 03:35 4 03:46 4 00:03:46	00:23 6 00:27 7 00:16 7 00:18 2 00:21 6 00:10 2 00:22 5 00:17 6 00:15 1 00:14 5 00:30 5 00:11 4	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	11								
5	VICTOR RUANO JIMÉNEZ ...	00:04:02	14:44:17	00:20 5 00:37 3 00:55 4 01:23 4 01:47 4 01:58 5 02:18 4 02:39 5 02:57 5 03:13 5 03:51 5 04:02 5 00:04:02	00:20 5 00:17 2 00:18 9 00:28 7 00:24 8 00:11 5 00:20 3 00:21 9 00:18 4 00:16 6 00:38 7 00:11 4	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	20								
6	JUDITH DOMÍNGUEZ TOLED...	00:05:06	14:36:23	00:41 8 00:41 11 00:13 2 00:26 6 00:47 3 00:11 5 00:26 8 00:19 8 00:35 10 00:12 1 00:53 11 00:12 6 00:05:06	00:41 8 00:23 8 00:35 8 00:03 7 00:18 7 00:29 6 00:25 6 00:14 6 00:48 6 00:01 6 00:54 6 00:06 6 00:06 6	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	10								
7	ANTONIO SEGURA GARCÍA ...	00:06:02	14:29:17	00:30 7 00:37 9 00:16 7 00:42 9 01:08 14 00:10 2 00:21 4 00:33 14 00:28 9 00:16 6 00:48 9 00:13 8 00:06:02	00:30 7 00:07 7 01:23 7 02:05 8 03:13 8 03:23 8 03:44 8 04:17 8 04:45 7 05:01 7 05:49 7 06:02 7 06:02 7	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	21								
8	CARLOTA TORRADO GARCÍA...	00:06:36	14:30:06	01:33 10 02:13 10 02:41 9 03:41 9 04:00 9 04:19 9 04:47 9 05:04 9 05:30 9 05:48 9 06:21 8 06:36 8 00:06:36	01:33 10 00:40 10 00:28 11 01:00 11 00:19 5 00:19 10 00:28 11 00:17 6 00:26 7 00:18 8 00:33 6 00:15 11	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	23								
9	JOSÉ PLASENCIA FULIDO ...	00:06:41	14:24:36	01:31 13 03:08 13 03:20 12 04:03 11 04:31 11 04:46 11 05:10 10 05:25 10 05:50 10 06:10 10 06:31 9 06:41 9 00:06:41	01:31 13 01:17 13 00:11 1 00:43 10 00:28 10 00:15 9 00:24 7 00:15 5 00:25 6 00:20 11 00:21 2 00:10 1	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	15								
10	PEDRO RODRÍGUEZ DE RIV...	00:07:11	14:44:26	00:18 3 00:14 6 00:24 10 00:30 8 00:29 11 00:28 11 00:26 8 00:25 10 01:34 14 00:19 9 01:25 14 00:29 12 00:07:11	00:18 3 00:03 00:01 00:15 00:13 00:10 00:06 00:02 00:10 00:08 00:00 00:00 00:00 00:00 00:00	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	17								
11	NIKHIL MANTANI MANTANI...	00:07:44	14:22:07	01:44 12 02:06 9 03:23 13 03:46 10 04:19 10 04:31 10 05:12 11 05:40 11 06:19 11 06:38 11 07:10 11 07:44 11 00:07:44	01:44 12 00:22 5 01:17 14 00:23 4 00:33 12 00:15 7 00:41 14 00:28 11 00:39 12 00:19 9 00:52 10 00:14 10	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	13								
12	CHRISTIAN DOMÍNGUEZ DEN...	00:10:52	14:13:59	01:42 11 03:14 14 04:08 14 04:09 13 04:33 13 04:47 13 05:27 13 05:47 12 06:32 12 06:43 12 06:48 12 06:58 12 00:10:52	01:42 11 01:34 15 00:52 13 01:01 12 01:13 14 00:34 12 00:40 13 00:30 12 00:35 10 00:39 14 01:04 12 00:37 13	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	9								
13	SICHMARTA DÍAZ PÉREZ ...	00:11:46	14:10:49	01:28 9 02:49 11 03:19 11 05:19 14 07:13 14 07:58 14 08:17 14 09:18 14 10:04 14 10:27 14 11:34 14 11:46 13 00:11:46	01:28 9 01:21 14 00:30 12 02:00 15 01:54 15 00:45 14 00:49 15 00:31 13 00:46 13 00:23 13 01:07 13 00:12 6	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	5								
14	ZORAINA RAQUEL ARIAS R...	00:12:08	14:06:56	01:11 01:07 00:17 01:42 01:39 00:35 00:31 00:18 00:31 00:18 00:31 00:18 00:31 00:11 00:52 00:02 00:12:08	01:45 15 04:37 15 06:23 15 07:25 15 07:48 15 08:25 15 08:52 15 09:06 13 09:23 13 09:33 13 10:38 13 12:08 14 00:12:08	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	1								
	KILLIAN RIVERO HERNÁNDEZ	DQ	14:25:17	02:20 14 02:53 13 03:07 10 04:18 12 04:43 12 06:16 12 06:46 12 09:16 15 00:00 00:00 00:00 00:00 00:00	02:20 14 00:33 8 00:14 4 01:11 14 00:25 9 01:33 15 00:30 12 02:50 15	00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00 00:00	16								
	Ideal time:			00:13 00:14 00:12 00:13 00:15 00:09 00:17 00:12 00:15 00:12 00:15 00:10 00:02:39											

Fig.3 Totals and records partial results

## 6. Experience 2: Virtual Orienteering

In this experience there were 33 students taking part in it, including 12 women and 21 men. The average age and standard deviation were 18.8 (1.4) between 18 and 24 years old. Like in previous case, no participant had any experience in orienteering sports and involvement was also encouraged with a marks' upgrade in the same conditions of the previous experience.

The first phase of this experience took around 90 minutes and consisted once again on a classroom explanation of the orienteering sport's basics as well as the compass' use and further guidance about use of the given software. The demo version of the Catching Features program was used and despite being freeware, it included every single feature we needed: <http://www.catchingfeatures.com/>.

Catching Features is an orientation game where one or several players get immersed in a virtual environment. Players take part in several races using a topographic map with their key and compass as a real race.

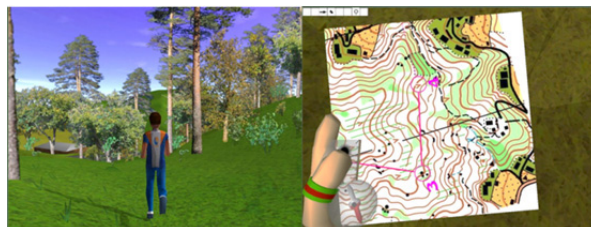


Fig.4 Catching features settings



The game also offers the chance to play on a single player mode or multiplayer against other participants. In the full version there are also online games available. Settings are quite realistic as the player can move and have points of view across every single direction. Every beacon can be found using the key and compass until the itinerary is complete.

In our experience we ask the students to complete a minimum of six races. They had one week to finish them and they performed them at their own homes through their own computers downloading the game's free trial version.

Catching Features provides several start formats with results obtained in different races. So, a file with the full results was requested to the students for evaluating the experience's performance and applying the incentives.



Fig.5 Student results

## 7. Measures and Results

In table 1 we find the results obtained by the students in the Perspective Taking Test before and after training for the three groups: Real Orienteering, Virtual Orienteering and Control Group. Mean values prior to training are quite similar in all three groups.

Table 1. Values Pre/Post Test and Gain Scores

	Pre-Test	Post-Test	Gain
Real Orienteering Group	42.33	18.75	23.58
Virtual Orienteering Group	54.77	24.00	30.77
Control Group	54.29	45.65	8.64

An analysis of variance (ANOVA) was carried out with all data obtained from the three groups in the Perspective Taking and Spatial Orientation Test, showing there is no statistical difference between groups prior to this training. So the three groups were statistically equivalent about spatial orientation at the beginning of this study.

We compared the mean values obtained in the pre and post test using the t-Student paired series test and data for the real orienteering group were  $t=8.08$ ,  $p\text{-value}=0.00$ ; for the virtual orienteering group  $t=11.90$ ,  $p\text{-value}=0.00$  and finally the control group obtained a  $p\text{-value}=0.27$ .

The groups performing these trainings showed a statistical improvement in their spatial orientation levels. The p-values are below 5% statistical significance which means that any student who performs one of both

trainings has a chance over 95% of improving their spatial orientation levels. Besides, the results show there is no improvement in the spatial orientation levels for the control group.

For comparing and checking out if there is any difference between both groups, we carried out the Sefflé contrast over multiples choices.

Table 2. Groups comparison.

(I) group	(J) group	Difference between mean values (I-J)	Typical error	Sig.	Confidence interval at 95%	
					Upper limit	Lower limit
1	2	-7.18848	3.49433	.128	-15.9131	1.5361
	3	18.52125(*)	4.28814	.000	7.8146	29.2279
2	1	7.18848	3.49433	.128	-1.5361	15.9131
	3	25.70973(*)	4.21981	.000	15.1738	36.2457
3	1	-18.52125(*)	4.28815	.000	-29.2279	-7.8146
	2	-25.70973(*)	4.21981	.000	-36.2457	-15.1738

\*Difference between mean values is significant at .05 level.

1(Real Orienteering), 2(Virtual Orienteering), 3(Control Group)

The results show there is no significant difference between the control group and those groups performing the training. Besides, there is no difference between the groups undertaking training in both the real and virtual environments. This means that improvement in spatial orientation is similar performing any of both trainings.

## 8. Conclusions

Even obtaining the results described in previous section, where we saw that students improved their spatial orientation in any of both trainings, we must consider certain questions while we approach the new experience in subsequent academic courses. Despite how precise and realistic the environment's simulation is, we must consider the fact that people is used to move through a real environment. Despite the visual information available, the field of view in the real world is much wider than in the virtual one, so the spatial information output is much lower in the virtual environment and the update of our body's location may come not only from the visual system but the kinesic one as well. Besides, while in a real environment we need an auto-directed movement from our body, in the virtual one the experience is far more passive.

From the teacher's point of view, it was easier to prepare and perform the virtual experience. Aside from the fact of learning the orienteering race basics and handling the Catching Features app, there was no other relevant issue. However, the preparation of the experience in a real environment held at a football field required not only a great organizational capabilities but also putting together services and staff from the Las Palmas de Gran Canaria University.

From the student's point of view, we received positive feedback; both tests were attractive for them and they performed them enthusiastically and willingly although as we previously mentioned, they were encouraged with a mark's upgrade if they reached the top three. We were surprised by the positive welcome and assessment that the real field test, the orienteering race, had. The interaction component and interpersonal competition got students so involved that they wanted to perform similar tests and showed great interest about the spatial abilities in their curriculums.

## Acknowledgements

We wanted to express our most sincere gratitude to Mr. Ulises Ortiz for his support whilst designing the orientation race and making the Sportident system available for acquiring all data from the test. His vast experience in this sport eased the design of the experience in the real field helping to perform it efficiently. We also would like to mention all students taking part in this experience as they showed great enthusiasm and collaboration during the whole test.

## Bibliography

- [1] Allen GL. Functional families of spatial abilities: Poor relations and rich prospects, *International Journal of Testing* 2003; **3**(3): 251-262.
- [2] Linn MC, Petersen AC. Emergence and characterization of sex differences in spatial ability: A meta-analysis, *Child Dev.* 1985; 1479-1498.
- [3] Lohman DF. Spatial abilities as traits, processes, and knowledge. 1988.
- [4] McGee MG. Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences, *Psychol.Bulletin* 1979; **86**: 889-918.
- [5] Maier PH, Spatial geometry and spatial ability—How to make solid geometry solid, In *Selected papers from the Annual Conference of Didactics of Mathematics* 1996, pp. 63-75.
- [6] Mafalda R. Efeitos do uso de diferentes métodos de representação gráfica no desenvolvimento da habilidade de visualização espacial, Thesis doctoral. Sao Paulo. (2000).
- [7] Carroll JB, Human cognitive abilities, Cambridge University: Press Cambridge 1993.
- [8] Hegarty M, Waller D. Individual differences in spatial abilities, In *The Cambridge handbook of visuospatial thinking*, 2005, 121-169.
- [9] Golledge RG, *Spatial Behaviour: A Geographical Perspective*, Guilford Press 1997.
- [10] Hegarty M, Richardson AE, Montello DR, Lovelace K, Subbiah I. Development of a self-report measure of environmental spatial ability, *Intelligence* 2002; **30**: 425-447.
- [11] Montello DR, Scale and multiple psychologies of space. In *Spatial information theory a theoretical basis for gis*, 1993, pp. 312-321. Springer Berlin Heidelberg.
- [12] Allen GL. Functional families of spatial abilities: Poor relations and rich prospects, *International Journal of Testing* 2003; **3**: 251-262.
- [13] Allen GL, Kirasic KC, Dobson SH, Long RG, Beck S. Predicting environmental learning from spatial abilities: An indirect route, *Intelligence* 1996; **22**: 327-355.
- [14] Montello DR, Lovelace KL, Golledge RG, Self CM. Sex Related Differences and Similarities in Geographic and Environmental Spatial Abilities, *Ann.Assoc.Am.Geogr.* 1999; **89**: 515-534.
- [15] Kozhevnikov M, Hegarty M. A dissociation between object manipulation spatial ability and spatial orientation ability, *Mem.Cognit.* 2001; **29**: 745-756.
- [16] Hegarty M, Waller D. A dissociation between mental rotation and perspective-taking spatial abilities, *Intelligence* 2004; **32**: 175-191.